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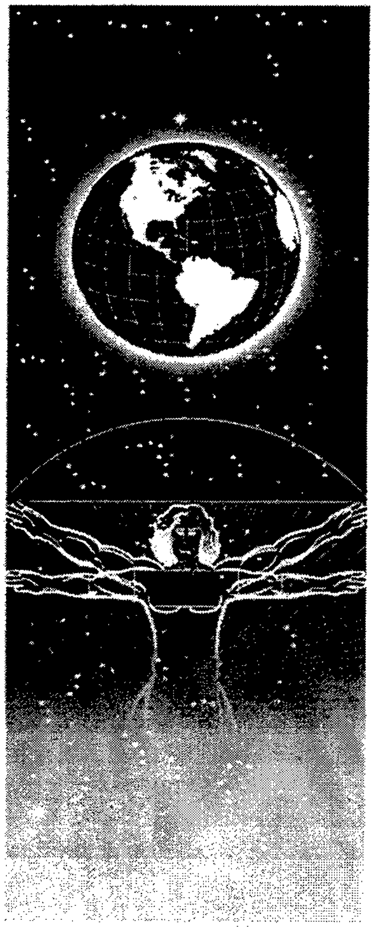

UNITED STATES AIR FORCE RESEARCH LABORATORY

An Improved Takeoff Roll Noise Model for NOISEMAP 6.2

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September 1992

Interim Report for the Period September 1991 to September 1992

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

MARIS M. VIKMANIS
Chief, Crew System Interface Division
Air Force Research Laboratory

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13. ABSTRACT *(Maximum 200 words)*

The modeling of noise of stationary aircraft prior to and during its takeoff roll is one of the many elements included in NOISEMAP. This report describes the current Takeoff Roll Model contained in NOISEMAP. Features of this model include static ground runup, its associated directivity pattern, and adjustments because of the acceleration of the aircraft during takeoff roll.

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PREFACE

The work reported herein was performed by Wyle Laboratories, 128 Maryland Street, El Segundo CA, from September 1991 to September 1992 under Air Force contract F33615-89-C-0531 for the Armstrong Laboratory, AL/OEBN, Wright-Patterson Air Force Base OH. This effort is part of Program Element 62202F, Work Unit 72313411, and was monitored by Robert A. Lee.

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1.0 INTRODUCTION

Models for the prediction of aircraft noise exposures around airfields need to account for a considerable range of operational and noise emission characteristics which occur during aircraft takeoffs and landings at the airfields. Computer models, such as the Air Force NOISEMAP program[1], typically accommodate these characteristics either by invoking specific algorithms which model the characteristics, or by incorporating specific features in an aircraft noise database which can be used by the program.

The modelling of noise characteristics caused by a stationary aircraft prior to its takeoff roll, and subsequently during its accelerating ground roll to the liftoff point on the runway, is one of the many elements included in programs such as NOISEMAP. Specifically, the NOISEMAP program uses a Takeoff Roll Model (TRM) that is invoked by the program when a departure flight case is identified (as compared with a landing or a touch-and-go closed pattern operation). The implementation of the TRM in NOISEMAP is incurred by means of a flag in the input file (XNMI) called TOROLL which indicates either ON or OFF. This is automatically set on when the initial departure airspeed is zero and turned off when the flight operation to be analyzed is a landing or a touch-and-go operation.

When invoked, the TRM is a combination of three different noise factors, namely:

(i) the reference ground-to-ground noise levels for the aircraft at the designated power and airspeed at liftoff,

(ii) an array of noise level directivity adjustments, denoted herein as DA, that are applied to item i, and

(iii) a calculated adjustment which accounts for the noise level variation due to the aircraft accelerating down the runway to rotation.

The NOISEMAP reference noise levels are those listed in the input file (NMI) for ground-to-ground propagated values of SEL (or EPNL if computing NEF) at the 22 standard distances, these having been computed by the OMEGA 10 preprocessor program. The array of fixed-source adjustments (FA) that are used to simulate a static runup directivity is contained in the program as a set of values equally applicable to all military aircraft at all takeoff power settings. It is listed in Table 1-1 of this report and shown graphically in Figure 1-1 as applied to the ground-to-ground reference data for a KC-135 transport aircraft at takeoff power.

Table 1-1

Fixed-Source Adjustments (FA Array)

(Amended from Reference 1, and as Currently Used in NOISEMAP 6.2)

Distance ft	Azimuthal Angle Relative to Aircraft Forward Axis								
	0°	20°	35°	50°	70°	90°	110°	130°	180°
200	12.6	12.6	9.8	9.0	6.8	7.2	7.1	9.6	1.6
250	12.5	12.5	9.7	8.7	6.6	7.0	7.1	9.5	1.5
315	12.4	12.4	9.4	8.3	6.3	6.8	7.0	9.3	1.3
400	12.1	12.1	9.1	7.8	5.8	6.4	6.8	9.0	1.0
500	11.8	11.8	8.6	7.1	5.3	5.9	6.4	8.5	0.5
630	11.4	11.4	8.0	6.4	4.7	5.4	6.1	8.0	0
800	10.5	10.5	7.0	5.2	3.6	4.4	5.3	7.1	-0.9
1000	10.1	10.1	6.4	4.3	2.9	3.8	4.9	6.6	-1.4
1250	9.4	9.4	6.7	3.3	2.0	3.0	4.4	5.6	-2.1
1600	8.4	8.4	4.7	1.9	0.9	2.1	3.7	5.1	-2.9
2000	7.2	7.2	3.4	0.2	-0.5	0.9	2.8	4.0	-4.0
2500	6.0	6.0	2.1	-1.5	-1.6	-0.1	2.1	3.2	-4.8
3150	4.2	4.2	0.2	-3.8	-3.0	-1.2	1.4	2.2	-5.8
4000	1.1	1.1	-2.3	-7.2	-4.4	-2.2	0.3	1.4	-6.6
5000	0	0	-7.6	-24.4	-5.3	-2.3	0.6	1.5	-6.5
6300	0	0	0	0	-7.0	-2.6	0.6	1.2	-6.8
8000	0	0	0	0	-10.4	-3-3	0.4	0.8	-7.2
10000	0	0	0	0	0	-3.8	0.3	0.5	-7.5
12500	0	0	0	0	0	-4.5	0.2	0	-8.0
16000	0	0	0	0	0	-5.2	0.1	-0.4	-8.4
20000	0	0	0	0	0	-5.5	0.3	-0.5	-8.5
25000	0	0	0	0	0	-5.6	0.6	-0.6	-8.6

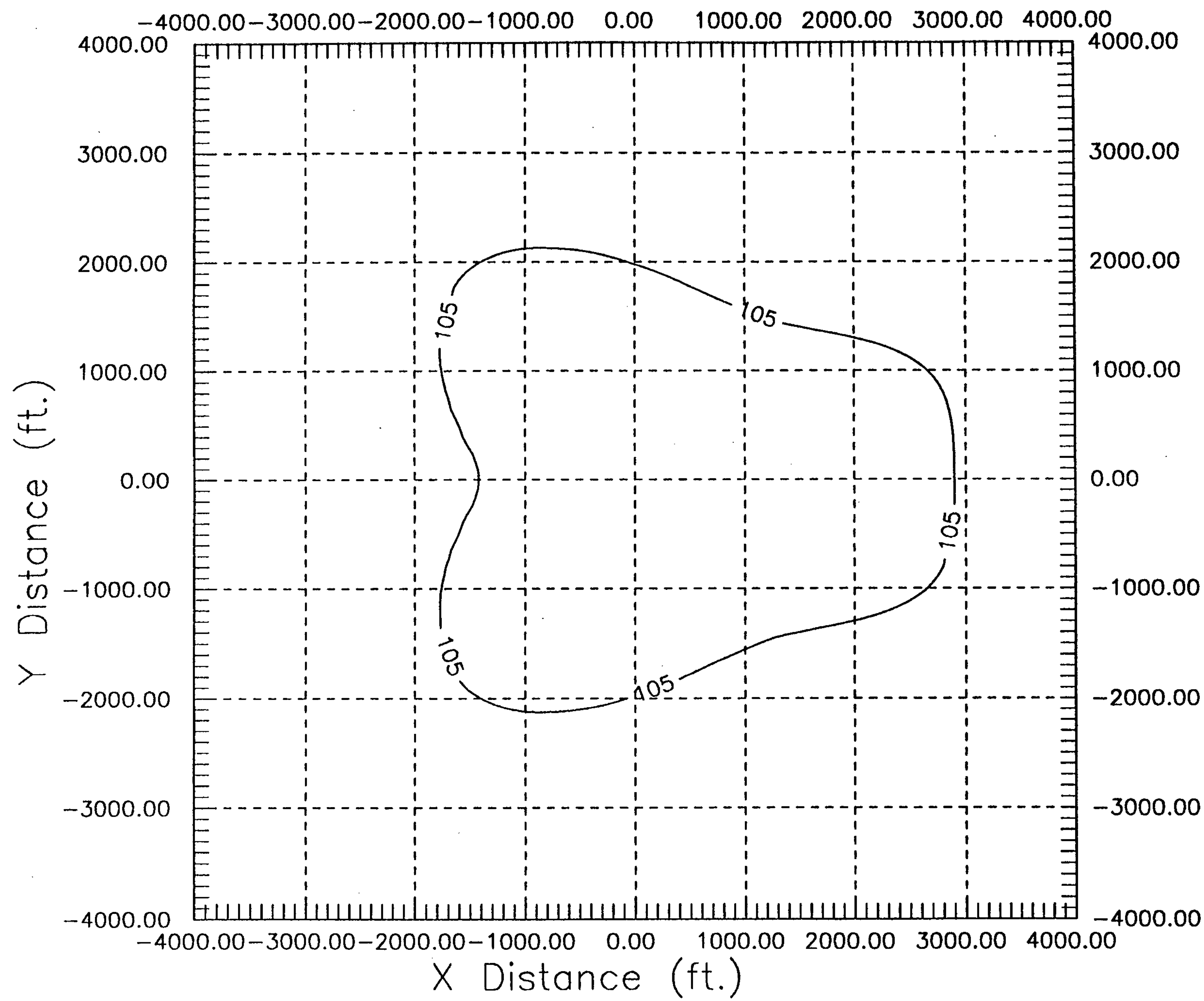

Figure 1-1. Static Runup 105 dB Contour for C135A at 96% RPM, Using Current FA Array

The acceleration correction, denoted here as D6,is a unique component of the TRM, the current version of which is described in Reference 2 and discussed further in this report. In essence the correction was derived from limited noise data obtained for a Boeing 707 aircraft, and is of the form:

$$D6 = 5 \log_{10}\left(\frac{5.357}{f}\right) - 10 \log_{10}\left(\frac{V_{ref}}{160}\right) \quad , \quad dB \tag{1}$$

where $f = (V_2 + 10)^2 / S_o$

$V_{ref} = V_2 + 10$ = takeoff speed in knots

S_o = takeoff roll distance to liftoff (in feet).

The ratio 5.357/f is simply the ratio of accelerations, from static to rotation, of the Boeing 707 and the aircraft being modelled. That is,

$$f = 2a = (V_2 + 10)^2 / S_o$$

assuming constant acceleration, a.

The 10 $\log_{10}$ (V_{ref}/160) term (now obsolete) was a correction to account for the difference between takeoff speed and the speed (160 kts) for which reference noise data were available. However, modifications have been made to the NOISEMAP program since the development of this expression. These changes are such that the 10 $\log_{10}$ (V_{ref}/160) term is no longer applicable and V_{ref} is the liftoff speed used in compiling the SEL values for the liftoff condition.

The current expression for D6 is therefore:

$$D6 = 5 \log_{10} (5.357\, S_o) - 10 \log_{10} V_{ref}, \ dB \tag{2}$$

and is applied to the ground-to-ground propagated SEL values in the input (NMI) file for the aircraft at takeoff power and liftoff speed, to obtain the corresponding SEL value at start of roll (V = 0).

Thus, the static noise "directivity" pattern can be described as:

$$SEL^{gg}_{V=0} (r,\theta) = SEL^{gg}_{V=V_{ref}} (r) + FA (r,\theta) + D6 (V_{ref}, S_o), \quad dB \tag{3}$$

where r is the propagation radius and θ is the azimuth angle relative to the forward axis.

When the aircraft commences motion, the NOISEMAP noise exposure model no longer comprises a directional pattern, but simply consists of a sideline SEL value appropriate to the sideline distance d, between the grid point (receiver) location and the ground roll path of the aircraft. A new D6 can be calculated for other aircraft positions along this ground roll path, this value being:

$$D6 = 10 \log_{10}\left(\frac{V_{ref}}{V}\right), \quad dB \tag{4}$$

where V is the aircraft speed (knots).

The appropriate SEL value at some sideline distance, d, during the ground roll is:

$$SEL_v(d) = SEL^{GG}_{v=V_{ref}}(d) + D6\,(v, V_{ref}), \quad dB \tag{5}$$

After liftoff, the noise prediction procedure reverts to the flyover or flyby model which is not discussed herein.

The purpose of this report, therefore, is to reexamine and refine the takeoff roll noise model used in previous and current versions of NOISEMAP and to demonstrate the effects of potential revisions on the noise exposure calculations.

2.0 TAKEOFF NOISE MODEL COMPONENTS

2.1 Static Aircraft Noise

As discussed in the preceding section, the directivity pattern for the noise emissions from military aircraft prior to to takeoff roll is currently a fixed array of adjustment values (Table 1-1) which apply at various radii and azimuthal angles around the static aircraft as shown in Figure 1-1.

Since the development of this model in 1976, other similar directivity models have been developed for civilian (jet) aircraft noise by the Society of Automotive Engineers[3] and by the Danish Acoustical Institute and U.K. National Physical Laboratory[4,5] while an extensive amount of literature also exists on the directivity patterns associated with propulsion fans and jets in static or forward velocity conditions.[6-13]

In general, it has been the case that the civilian fleet of aircraft is considered sufficiently amenable to a "fleet-averaged" model. However, it can be questioned whether such averaged models are applicable to the military fleet of aircraft, which includes a much wider variety of propulsion systems operating over a much wider range of takeoff power conditions. While the static noise directivity will commonly exhibit a lobed pattern, the relative magnitudes and angles of noise level maxima vary for propeller and jet aircraft and especially for jet aircraft at afterburner takeoff power settings.

The question to be addressed is whether a more refined directivity model for the static aircraft case (at takeoff power) is available and is worth implementing in NOISEMAP for improved cumulative noise exposure accuracy.

With regard to availability, there is one feature of NOISEMAP technology which is readily usable; that is, the capability of the OMEGA 11 program element to predict noise (and directivity patterns) for single engine ground run-up conditions on each aircraft type. This capability is based on a separate NOISEFILE[14] data base derived from noise measurements around static aircraft during engine maintenance tests. OMEGA 11 produces noise level data (in the form of A-weighted sound levels or perceived noise levels) at 22 reference distances and 10 azimuthal angles (0, 30, 40, 50, 80, 90, 100, 140, 150 and 180 degrees) relative to the aircraft engine forward axis. Examples of static noise patterns given by the OMEGA 11 program for takeoff power conditions are shown in Figures 2-1 to 2-4. It is readily evident that directivity is aircraft-specific and varies with power setting (such as military power versus

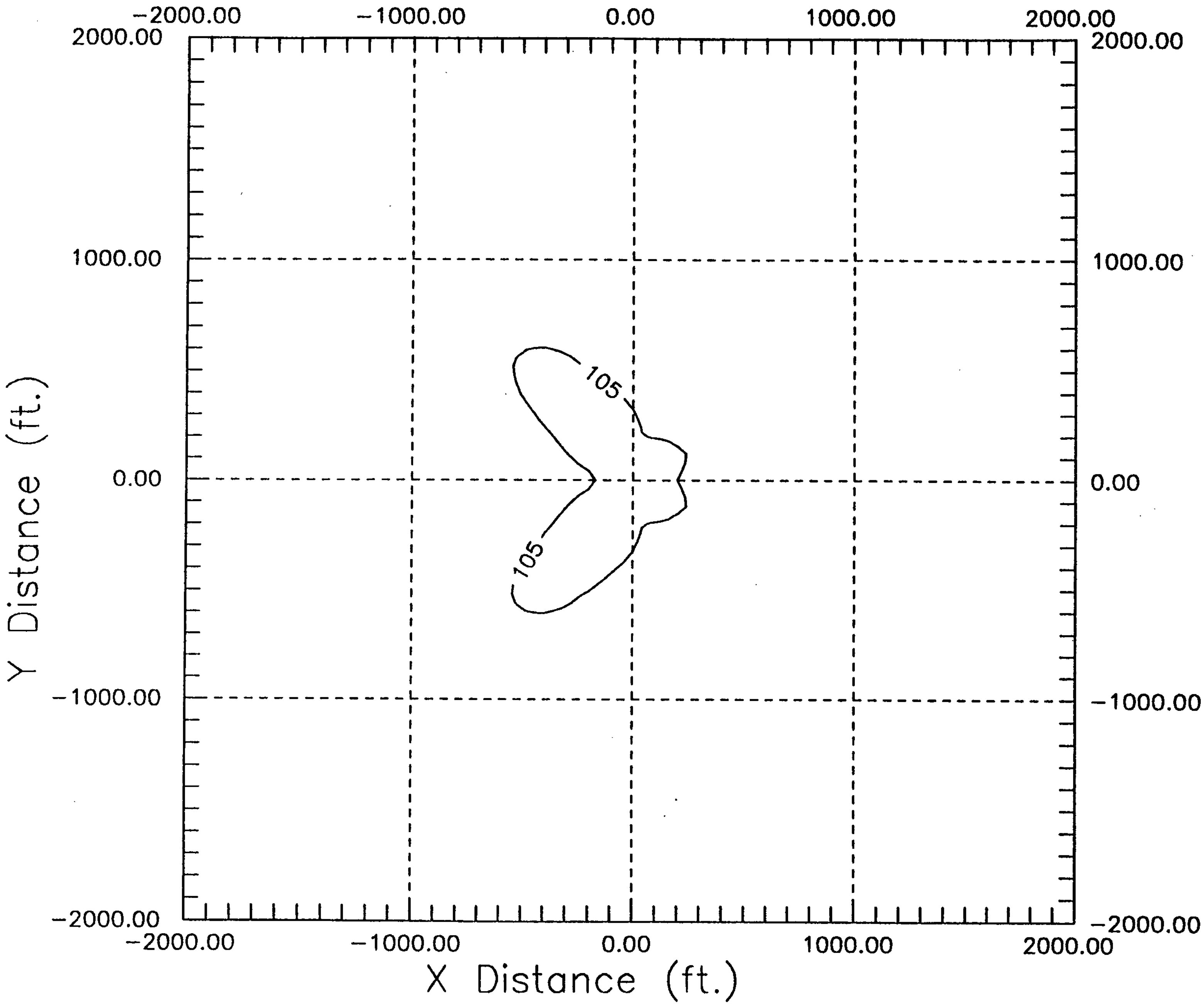

Figure 2-1. F-16 "Mil" Power Static Runup Contour at 105 dB(A), from OMEGA 11

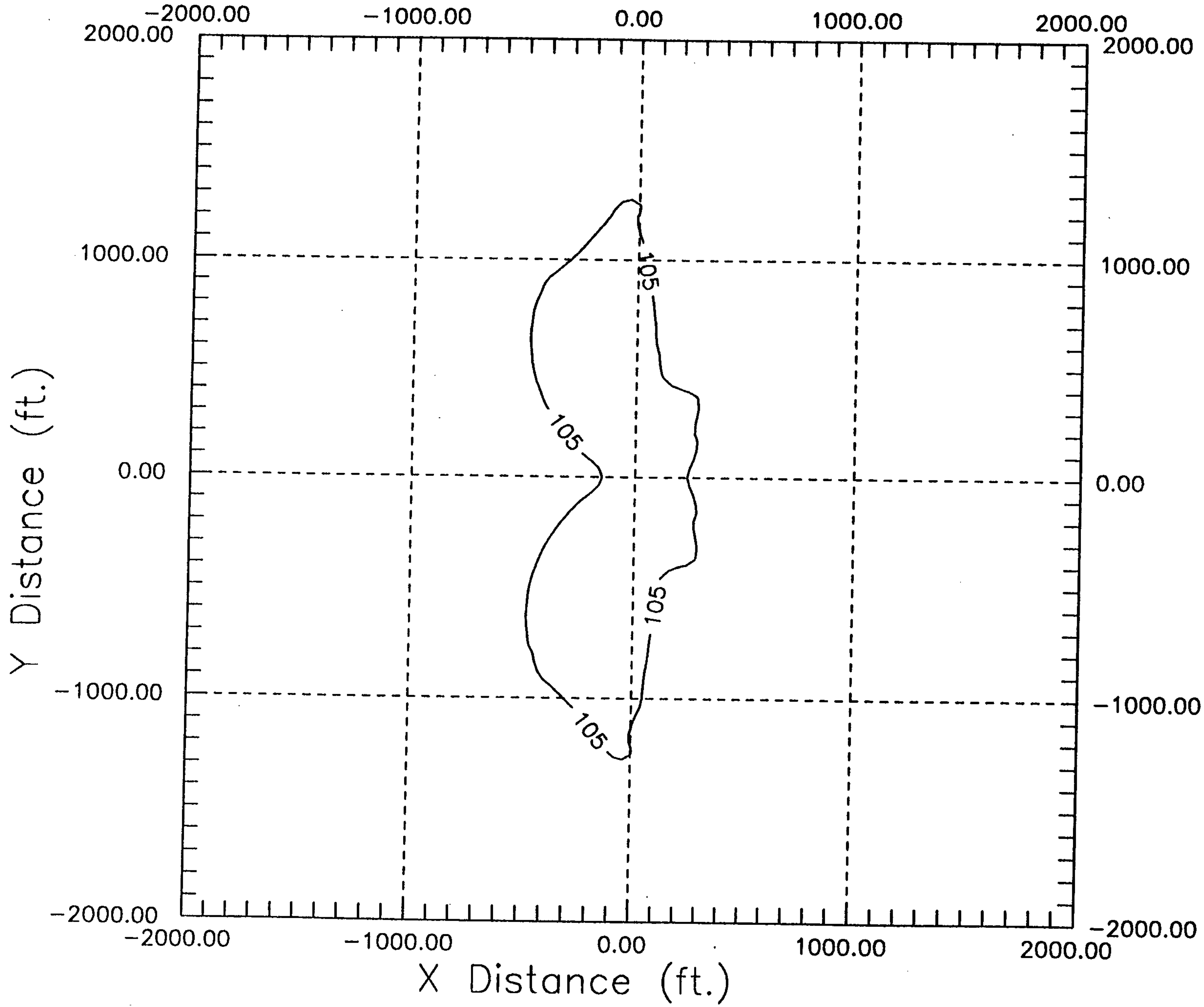

Figure 2-2. F-16 Afterburner Power Static Runup Contour at 105 dB(A), from OMEGA 11

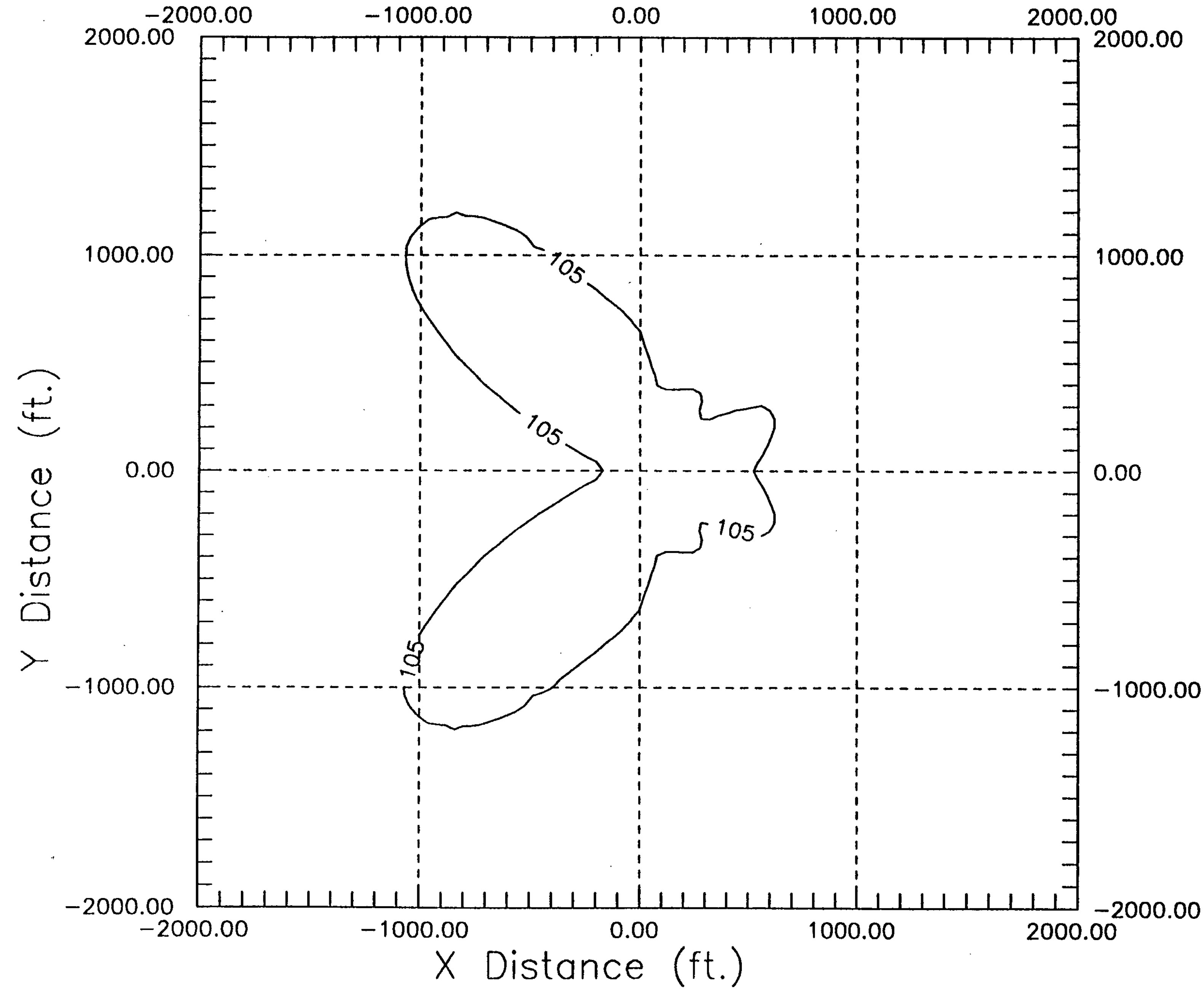

Figure 2-3. KC-135A Maximum Takeoff Power Static Runup Contour at 105 dB(A), from OMEGA 11

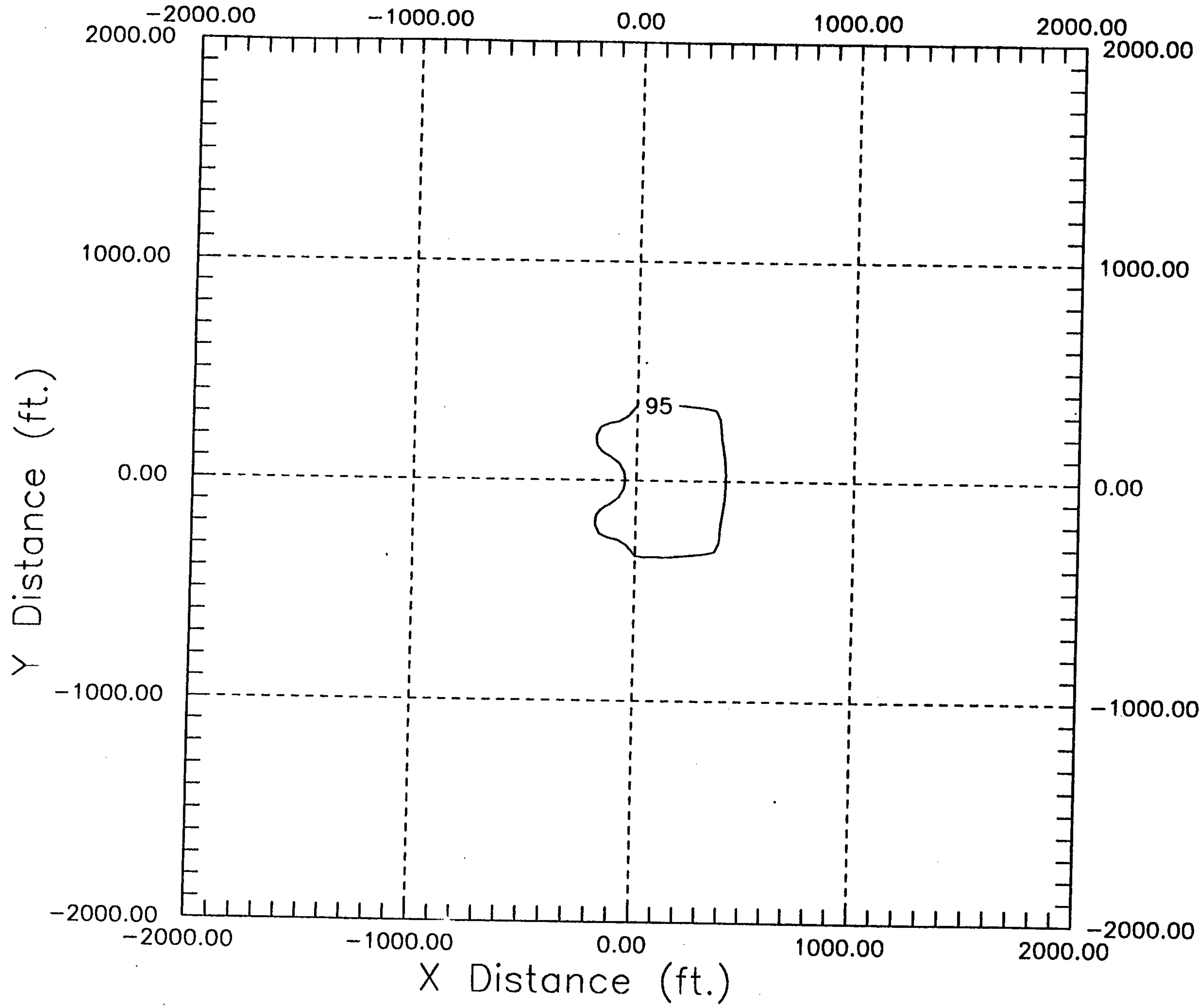

Figure 2-4. C-130A Maximum Takeoff Power Static Runup Contour at 95 dB(A), from OMEGA 11

afterburner for jets). While the Society of Automotive Engineers AIR 1845[3] document found a "fleet-averaged" model suitable for civil aircraft noise exposure modeling, these figures show that, for military aircraft, an aircraft-specific model would be much more appropriate.

However, the equally important aspect of the static engine noise model is to predict time-integrated noise metrics, such as SEL and EPNL, for the segment of the takeoff procedure prior to start of roll. For purposes of this report, this aspect will be addressed by reference only to the SEL metric, which is used in the evaluation of the Day-Night Average Sound Level for noise exposures around airports and airbases.

2.2 Forward Motion Effects

Databases for aircraft noise level are almost always derived from air-to-ground propagated overflight noise measurements. This reduces the amount of data necessary to compile a reference data set (for selected engine power settings and aircraft speeds) which can subsequently be extrapolated to other flight conditions and propagation angles relative to the ground plane. For takeoff roll noise, the extrapolation of the reference noise data involves:

- propagation over ground (i.e., ground-to-ground propagation),
- corrections due to the influence of aircraft speed (static through rotation speed) on the emitted noise and its directivity, and
- corrections due to the influence of aircraft speed on the time integrated metric, arising from the effect on the noise level time history (duration effect).

In the current NOISEMAP program, the effects of air and ground propagation are accommodated separately by the air-to-ground and ground-to-ground propagated SEL (or EPNL) obtained by means of OMEGA 10. Values of the (appropriate) time-integrated metric are contained in the NOISEMAP input file (for each of 22 reference distances) for each aircraft operation case at takeoff engine power and takeoff aircraft speed, in addition to other flight conditions. As discussed in Section 1.0, this reference noise condition is adjusted in NOISEMAP to give an SEL value adjacent to the takeoff roll position as:

$$SEL_v(d) = SEL^{GG}_{v=V_{ref}}(d) + D6\,(v, V_{ref}), \quad dB$$

during aircraft motion, and

$$SEL^{gg}_{V=0}\ (r,\theta) = SEL^{gg}_{V=V_{ref}}\ (r) + FA\ (r,\theta) + D6\ (V_{ref}, S_o), \quad dB$$

when the aircraft is at rest.

These two forms of the adjustment from the reference velocity noise data are intended to accommodate both the noise emission and noise duration effects.

In reality, however, the effects would normally be seen separately by reference to the change in the momentary noise metric values, such as the A-Weighted Sound Level, over a succession of time intervals. These momentary data are normally obtained by measurement, since the complex nature of the various propulsion noise sources requires extensive computational effort to provide an estimate of the time history of any specific noise metric for a given aircraft. However, the combination of experimental theoretical studies of various types of noise sources, from point sources to full expanded jet exhaust sources, has provided some clear indications of the effect of aircraft velocity on overall sound pressure levels from which expected trends in noise metrics can be postulated.

For jet aircraft noise, the predictive methodology of SAE ARP 876[11] has provided a continuing review of forward velocity effects. This has resulted in an expression for the overall sound pressure level difference:

$$SPL_{static} - SPL_{flight} = 10 \log_{10} \left[(V_j/V_{rel})^{m(\theta)} \, (1 - M_a \cos\theta) \right] \qquad (6)$$

where V_j is the absolute jet velocity,

V_{rel} is the relative jet velocity, equal to $V_j - V_{aircraft}$,

M_a is the aircraft Mach number, and

$m(\theta)$ is an exponent which varies with the angle θ relative to the forward axis and the jet Mach number.

The basic conclusion of these studies has been that forward motion:

- increases the SPL in the forward hemisphere of the radiation pattern, and
- decreases the SPL in the aft hemisphere of the pattern.

While this is true for jet noise, other components of the noise spectra, such as fan, compressor and turbine noise, are not so readily predictable for the forward motion case. Increases in tip speed at the fan and compressor stages of jet engines can be more than offset, in terms of noise generation, by improvements in aerodynamic flow.

A method described by the SAE for airplane noise in the vicinity of airports, SAE AIR 1845,[3] provides a velocity correction term which can be applied at incremental distances along the takeoff ground roll. This term is denoted ΔV, and is added to the reference (ground propagated) sound exposure level corresponding to takeoff power and takeoff velocity. The ΔV term uses a minimum ground roll speed of 32 knots and a normalization speed of 160 knots which corresponds to the noise level data base condition:

$$\text{(i.e., D6)} = \Delta V = 10 \log_{10} (160/V) \tag{7}$$

where

$$V = \sqrt{(32)^2 + (V_{tg}^2 - 32^2)\, x/S_g} \tag{8}$$

where x is the distance along the ground roll from brake release,

S_g is the total ground roll distance, and

V_{tg} is the true ground speed at takeoff.

Figure 2-5 shows the roll-off nature of this correction, from start of the ground roll to the liftoff point, for a takeoff speed V_{tg} equal to 160 kts. This could be adapted to NOISEMAP by using the takeoff speed (V_{ref}) as the reference speed (instead of 160 kts) for the SEL values employed by NOISEMAP during takeoff roll.

The Figure 2-5 model assumes constant acceleration throughout the ground roll for which the following relationship holds;

$$10 \log_{10} (V_{ref}/V) = -5 \log_{10} (x/S_g) \tag{9}$$

This expression can be used to translate other velocity dependency forms of D6 to their distance (x/S_g) dependent equivalents, provided of course that constant acceleration is assumed.

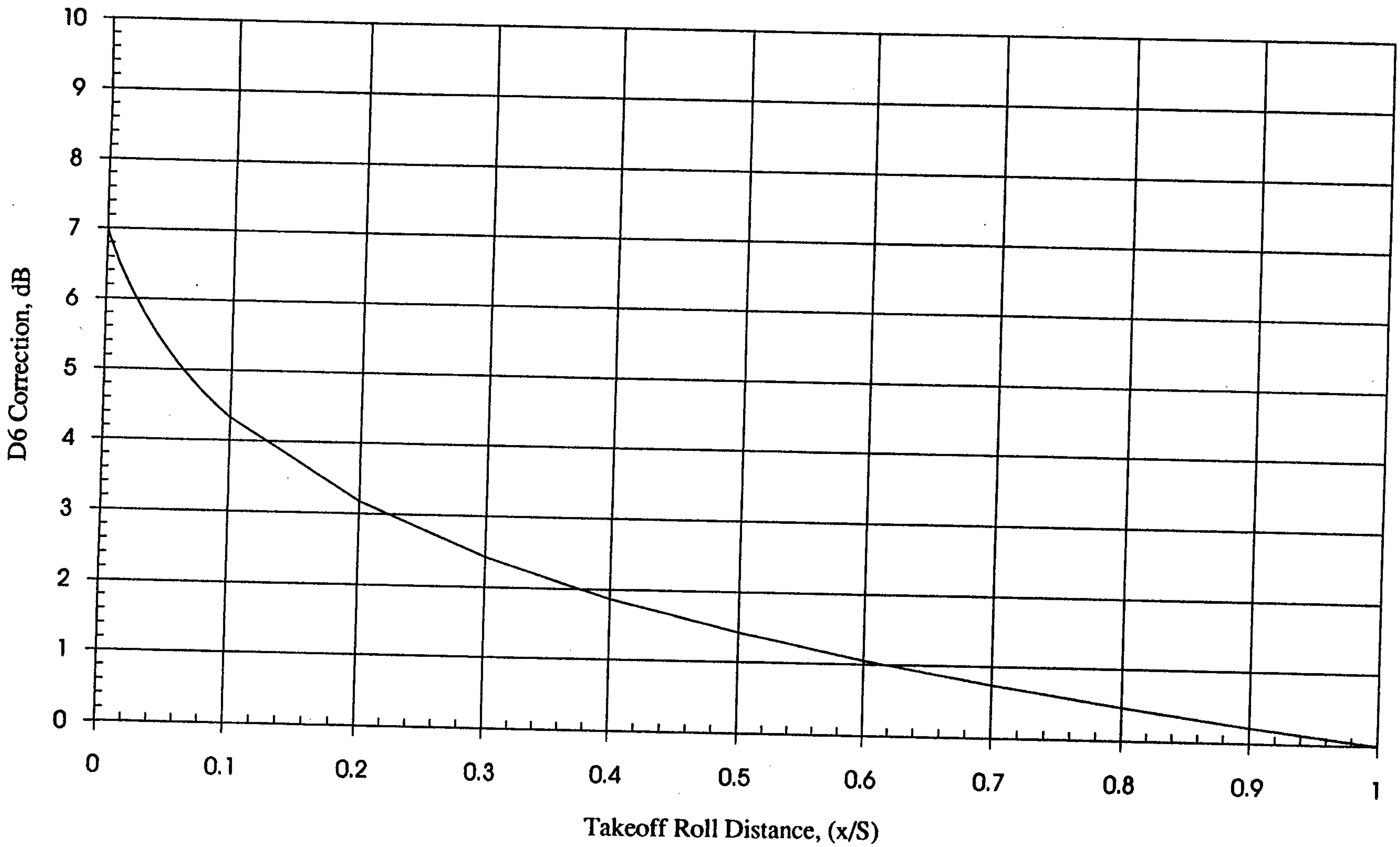

Figure 2-5. SAE AIR 1845 for D6 Correction During Takeoff Ground Roll

The 10 $\log_{10}$ V dependency is simply a result of the longer noise duration at lower pass-by speeds and basically neglects other physical mechanisms (such as Doppler amplification or relative jet velocity effects). These mechanisms have a small effect at low speeds during takeoff roll but can be significant at higher flight speeds.

Changes to the SAE AIR 1845[3] method have been mainly to accommodate a discrepancy in the prediction of "back-end" noise at civilian airports. These changes have been invoked by a reduction of the 32 knot minimum speed to 16 knots to achieve a more accurate static directivity pattern (which includes the ΔV term) in the FAA's Integrated Noise Model predictions.[15] This change would not, however, be applicable to OMEGA 11 "back-end" noise levels which are predicted as absolute values, rather than component levels.

More recent measurements conducted on civilian aircraft at Kastrup Airport, Copenhagen, and other European airports[4] have also shown a net result of decreased values of maximum A-Weighted Sound Level and Sound Exposure Level as the aircraft move from static to takeoff velocity. The conclusions of the Copenhagen study were based on an analysis of noise reduction as a function of change in airspeed[5]. These reductions, denoted in decibels per knot, were found to be 0.023 to 0.056 dB/kt for jet aircraft with old technology engines, and 0.015 to 0.052 dB/kt for aircraft with new technology jet engines. One of the latter which had pronounced tones in the noise spectrum was found to exhibit a noise increase with increased speed. This is a possible result of different source mechanisms being responsible for an increase in absolute local velocity, such as helical tip speed at the fan stage.

The application of these noise reductions to an aircraft with 160 knots speed at liftoff would give D6 values, at start-of-roll, of 3.7 to 9.0 dB for the old technology engines and 2.4 to 8.3 dB for new technology engines. These values tend to bracket that of the SAE model (7.0 dB) for the same condition.

In summary, there are a number of existing models for depicting the noise level change due to accelerating forward motion along the ground roll. The more complex of these are not suited for use in NOISEMAP due to their dependence on detailed aircraft information. The more simple appear to be too empirical to be applied to military aircraft without extensive measurement validation. A reasonable candidate for use in NOISEMAP would appear to be one of the forms used in SAE AIR 1845[3] which is examined further in Section 3.3.

3.0 RECOMMENDED MODEL

As described before, the NOISEMAP suite of programs contains an element which is specifically geared towards the generation of military aircraft run-up noise directivity. This is the OMEGA 11 component. The related run-up reference noise database was very carefully measured under controlled circumstances, and this component would be used to generate the static directivity pattern of military aircraft takeoff roll noise. Since there are no civil aircraft in the OMEGA 11 reference noise database, an alternative model must be used for civilian aircraft. The SAE 1845 model as used in the Integrated Noise Model (INM) would be a suitable alternative.

The effect of ground roll velocity on the sideline SEL values prior to liftoff would then be modeled by application of a revised D6 correction to the ground-to-ground propagated SEL values for the lift-power and speed.

3.1 Military Aircraft Static Directivity

Figures 2-1 to 2-4 show the static noise patterns of a jet attacked aircraft under military power and with afterburner, a jet-powered tanker, and a propeller-powered transport. As can be seen, these have quite dissimilar directivity patterns. The current NOISEMAP TRM uses a single directivity pattern for all military and civilian aircraft. The use of the OMEGA 11 reference data would provide an obvious increase in accuracy over the current model.

The OMEGA 11 database contains one-third octave band spectra of aircraft run-up noise at 19 angles (0 to 180 degrees in increments of 10 degrees). The OMEGA 11 program uses these data to calculate A-weighted (or PNL) levels at various aircraft power settings. The levels in the database represent the noise levels for one engine operating only. In order to use these OMEGA 11 data for military takeoff noise modeling, it will be necessary to assume that the whole aircraft static directivity of multi-engined aircraft is not appreciably different, and also that the levels achieved by operating N engines are accurately reflected by adding an adjustment of $10 \log_{10} N$ to the OMEGA 11 reference noise.

Both the OMEGA 10 and OMEGA 11 databases cover nearly all of the aircraft in the military fleet. Exceptions include the following:

a. The current OMEGA 10 flyover database includes the A-37 and C-17 aircraft which do not have entries in the OMEGA 11 run-up database.

b. Some aircraft designations that have specific entries in the OMEGA 10 flyover database (e.g., F-104G) do not have matching entries in the OMEGA 11 run-up database.

c. Some aircraft have surrogate data instead of actual measured data. This comes about when similar engines and configurations exist between aircraft or when measured levels are classified.

d. Power setting descriptions (e.g., % RPM) available in the OMEGA 10 database may not be available in the OMEGA 11 database or vice versa.

In order to overcome these incompatibilities the NOISEMAP 6.2 database will be revised to eliminate the inconsistent power types and to define surrogates for the OMEGA 10 aircraft that are missing in OMEGA 11.

Since the levels that are generated by the OMEGA 11 program are not integrated levels, some duration for the static engine run-up must be chosen. A consensus of historical data shows that a 5 second duration would be accurate in most cases. Some military departure procedures however, require up to a 1-2 minute static run-up before start-of-roll while a departure checklist is being completed. Since the point of entry of all aircraft operations data is through the BASEOPS program, this is the ideal place to enter data such operational details on the actual aircraft takeoff run-up duration. The BASEOPS program will therefore be modified to accomplish this task.

The original NOISEMAP takeoff roll model will be maintained for military aircraft without reference data in the OMEGA 11 database.

3.2 Civil Aircraft Static Directivity

Since there are no measured engine run-up data for civil aircraft in the OMEGA 11 database, an alternative methodology must be found for handling civil aircraft in NOISEMAP calculations. The SAE 1845 methodology used in the FAA's Integrated Noise Model (INM) was developed from a "fleet weighted average" of measured civil aircraft takeoff data taken at Boston Logan, Seattle Tacoma, and London Heathrow airports. The details of the model are presented in the SAE 1845[3] standard and are briefly outlined here.

The noise level adjustment (ΔL) for the civil aircraft directivity is determined by the following formula:

$$\Delta L = \begin{cases} 51.44 - 1.553\,\theta + 0.015147\,\theta^2 - 0.000047173\,\theta^3, & 90° \le \theta \le 148.4° \\ 339.18 - 2.5802\,\theta - 0.0045545\,\theta^2 + 0.000044183\,\theta^3, & 148.4 < \theta \le 180° \end{cases} \quad (10)$$

The angle $\theta = 0$ degrees is aligned with the nose of the aircraft pointing in the direction of takeoff.

3.3 Takeoff Ground Roll

As discussed in Section 2.2, models for the effect of aircraft speed on sideline Sound Exposure Level usually rely on a decrement in SEL at increasing speed due to reductions in noise duration. This is not necessarily true for all types of noise sources (as was found in the Copenhagen tests). However, despite the occasional exception, the generally observed rule is that the decrement is proportional to 10 $\log_{10}$ (speed ratio), as modelled in SAE AIR 1845 for both jet and propeller-driven aircraft.

The net change in SEL is due to an accumulation of effects which influence the time history of the A-weighted sound level during an aircraft pass-by. To explain this more clearly, it is probably beneficial to consider the Sound Exposure Level as a summation of two terms, namely, the energy in the 1-second time interval which contains the maximum A-Weighted Sound Level, and the energy in the time intervals before and after the maximum. That is,

$$SEL = L_{Amax} + 10 \log_{10} (E_s) \quad (11)$$

where E_s is the energy sum of A-weighted sound levels before and after L_{Amax}.

It is usual to restrict the measurement of E_s to the time interval containing the noise levels within 10 dB of the maximum level. This should provide an estimate of SEL which is within 0.5 dB of the long-term integrated value.

The effect of increased aircraft velocity on L_{Amax} is dependent on which noise source is dominant, but can be expected to show a net reduction due to reduced noise generation and a change in noise directivity pattern. This effect might be of the form:

$$\Delta_1 = K_1 \log_{10} (V_{ref}/V) \quad (12)$$

The change to the 10 log (E_s) term, which corresponds to SEL – L_{Amax}, is relatively well known for a change in forward velocity (V) and sideline distance (d) to be:

$$\Delta_2 \sim K_2 \log_{10} (d/V) \tag{13}$$

where $7 \leq K_2 \leq 10$.

Combining these effects of velocity to determine a suitable form for SEL might suggest that:

$$D6 = K_3 \log_{10} (V_{ref}/V) \tag{14}$$

at constant distance d and where K_3 most probably would exceed a value of 10.

Two examples of measured data which exhibit these characteristics during takeoff roll are shown in Tables 3-1 and 3-2. These tabulations contain SEL and L_{Amax} for a number of takeoff roll tests conducted by the Air Force at Wright-Patterson AFB.[16] The seven microphone locations were at 500 ft sideline to the runway centerline and spaced at 1000 ft intervals from adjacent to the start-of-roll (Mic 12), to some 6000 ft (Mic 18) in the direction of takeoff. Omissions at some microphone locations and some test runs indicate that no data were acquired or the data acquired did not include the time interval containing the pass-by L_{Amax} value.

These data, which are for a KC-135A jet transport aircraft and a C-130A propeller driven transport aircraft, show a consistent reduction in SEL and L_{Amax} during acceleration from microphone 13 to microphone 15 or 16 (close to the liftoff point). An increase at subsequent microphones (17 and 18) is due to a reduction in propagation losses as the aircraft rises above ground level.

In the tabulations, the difference in level between the pass-by value at each microphone and the minimum occurring over the range of microphones is denoted Delta SEL. These are indicative of the ΔV value incurred by change in aircraft velocity as it passes each microphone. As shown in both Table 3-1 and Table 3-2, the trend is towards a reduction in both SEL and L_{Amax} as aircraft velocity increases to liftoff speed (the reference speed).

An analysis of takeoff roll noise data, in the form of Delta SEL, for these two aircraft cases and also for C-18 and C-141 takeoff roll tests at WPAFB, shows that the reduction in SEL along the ground roll is not linear with respect to distance. Regression of Delta SEL values against log (x/S) for the microphones prior to the liftoff point and neglecting the static noise case, gives much greater coefficient values than have previously been proposed for this part of the noise model. Using the form,

Table 3-1

Takeoff Roll Noise Data for KC-135A Aircraft Tests

a/c Type	Run No.	Noise Measure	12	13	14	15	16	17	18
			Microphone No.						
			Distance from SOR						
			0	1000	2000	3000	4000	5000	6000
KC135	26	SEL	111.4	113.5	105.4	104.4	116.5	119.7	116.9
KC135	28	SEL	112.6	117.6	103.6	105.4	115.0	115.3	117.1
KC135	29	SEL	109.4	113.5	105.3	102.9	112.1	116.0	116.6
KC135	30	SEL	108.7	119.3	112.5	109.8	111.0	111.1	117.0
KC135	32	SEL	115.4	119.9	113.8	108.7	110.1	116.7	116.3
KC135	34	SEL	120.2	118.5	113.5	109.6	112.7	117.0	117.4
KC135	26	LAm	106.8	108.0	101.2	99.3	111.9	111.9	111.4
KC135	28	LAm	103.1	111.9	99.1	103.8	111.7	108.7	111.1
KC135	29	LAm	102.9	108.2	101.9	97.5	107.9	110.4	100.0
KC135	30	LAm	111.2	109.2	106.9	103.9	106.1	106.2	112.0
KC135	32	LAm	108.9	109.7	107.7	103.7	106.1	113.3	111.5
KC135	34	LAm	108.7	109.8	107.0	103.6	108.0	111.7	112.0
KC135	26	SEL - LAm	4.6	5.5	4.2	5.1	4.6	7.8	5.5
KC135	28	SEL - LAm	9.5	5.7	4.5	1.6	3.3	6.6	6.0
KC135	29	SEL - LAm	6.5	5.3	3.4	5.4	4.2	5.6	16.6
KC135	30	SEL - LAm	-2.5	10.1	5.6	5.9	4.9	4.9	5.0
KC135	32	SEL - LAm	6.5	10.2	6.1	5.0	4.0	3.4	4.8
KC135	34	SEL - LAm	11.5	8.7	6.5	6.0	4.7	5.3	5.4
		Average	8.9	7.6	5.0	4.8	4.3	5.6	7.2
KC135	26	Delta SEL	7.0	9.1	1.0	0.0	12.1	15.3	12.5
KC135	28	Delta SEL	9.0	14.0	0.0	1.8	11.4	11.7	13.5
KC135	29	Delta SEL	6.5	10.6	2.4	0.0	9.2	13.1	13.7
KC135	30	Delta SEL	-1.1	9.5	2.7	0.0	1.2	1.3	7.2
KC135	32	Delta SEL	6.7	11.2	5.1	0.0	1.4	8.0	7.6
KC135	34	Delta SEL	10.6	8.9	3.9	0.0	3.1	7.4	7.8
		Average	7.7	10.6	2.5	0.3	6.4	9.5	10.4

Table 3-2

Takeoff Roll Noise Data for C-130A Aircraft Tests

a/c Type	Run No.	Noise Measure	Microphone No. 12	13	14	15	16	17	18
		Distance from SOR	0	1000	2000	3000	4000	5000	6000
C130	14	SEL	109.5	99.0	93.7	92.5		95.8	
C130	15	SEL	109.5	102.0	93.5	93.2		95.4	
C130	16	SEL	109.0	101.2	93.5	93.5		95.2	
C130	17	SEL	109.2	101.0	93.7	93.0		94.8	95.8
C130	18	SEL	109.0	101.5	93.2	93.4		95.1	95.7
C130	19	SEL	109.1	98.7	92.6	93.0		96.7	
C130	14	LAm	96.0	93.2	88.5	87.6		91.9	
C130	15	LAm	96.1	94.3	88.0	88.2		91.4	
C130	16	LAm	96.9	93.7	89.4	89.0		91.4	
C130	17	LAm	95.6	95.4	89.3	87.9		90.8	91.9
C130	18	LAm	95.5	93.6	88.5	88.6		91.4	91.6
C130	19	LAm	95.9	93.3	88.5	88.1		93.7	
C130	14	SEL - LAm	13.5	5.8	5.2	4.9		3.9	
C130	15	SEL - LAm	13.4	7.7	5.5	5.0		4.0	
C130	16	SEL - LAm	12.1	7.5	4.1	4.5		3.8	
C130	17	SEL - LAm	13.6	5.6	4.4	5.1		4.0	3.9
C130	18	SEL - LAm	13.5	7.9	4.7	4.8		3.7	4.1
C130	19	SEL - LAm	13.2	5.4	4.1	4.9		3.0	
		Average	13.2	6.7	4.7	4.9		3.7	4.0
C130	14	Delta SEL	17.0	6.5	1.2	0.0		3.3	
C130	15	Delta SEL	16.3	8.8	0.3	0.0		2.2	
C130	16	Delta SEL	15.5	7.7	0.0	0.0		1.7	
C130	17	Delta SEL	16.2	8.0	0.7	0.0		1.8	2.8
C130	18	Delta SEL	15.8	8.3	0.0	0.2		1.9	2.5
C130	19	Delta SEL	16.5	6.1	0.0	0.4		4.1	
		Average	16.2	7.6	0.4	0.1		2.5	2.6

$$D6 = -K_4 \log_{10}(x/S) \quad (15)$$

for $0 < x/S \leq 1$, the values of K_4 obtained by regression are as listed in Table 3-3.

Table 3-3

Evaluation of Log Distance Coefficient K_4 for Takeoff Roll Noise

Aircraft	K_4	R^2 *
C-130	16.5	0.83
KC-135	21.2	0.81
C-141	17.9	0.42
C-18	12.6	0.68
All	18.4	0.34
All except C-141	19.4	0.47

*Square of correlation coefficient.

As discussed in Section 2, the assumption of constant acceleration from the start-of-roll to the liftoff point provides a relationship between velocity and ground roll distance dependency. Thus values of K_4 of (say) 15 and 20 would suggest velocity dependencies of $30 \log_{10}(V_{ref}/V)$ and $40 \log_{10}(V_{ref}/V)$ respectively, which are well in excess of the SAE model (i.e., $10 \log_{10}(V_{ref}/V)$).

Since values of Delta SEL at start-of-roll did not exceed 20 dB except in the case of the C-130 aircraft noise, it is clearly inappropriate to accept that a high value of K_4, of the order of 20, should be implemented without further justification. Figure 3-1 shows the results of the above Delta SEL model using K_4 values of 5 and 15. The lower value is implemented for purposes of model demonstration and is obviously a conservative compromise pending further investigation.

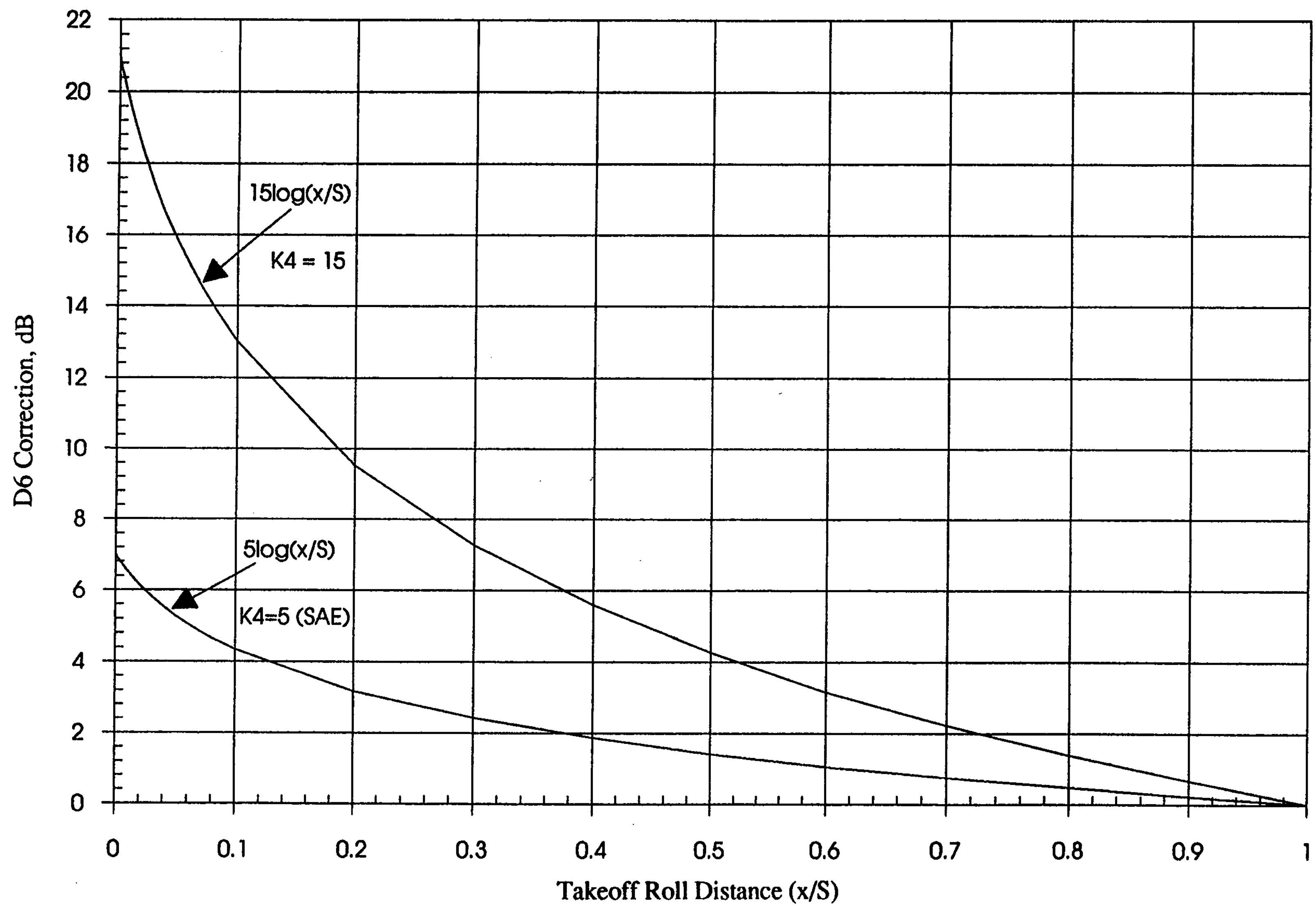

Figure 3-1. Implications of Using Different K_4 Coefficients for Ground Roll Dependency

4.0 IMPLEMENTATION INTO NOISEMAP

Implementation of the new takeoff roll model requires modifications to three elements of NOISEMAP. These are BASEOPS, the Master Control Module (MCM) and the NMAP program.

4.1 Implementation into BASEOPS

The BASEOPS program will be modified to include a static run-up duration for takeoff operations during the entry of the power profile data. This new data will be included in the BASEOPS Source (BPS) file in the flight power profile section, just before the power type descriptor, e.g.,

POWERID 33 8 15 % RPM,

where	POWERID	=	Power identifier,
	33	=	Aircraft code,
	8	=	the number of power entries,
	15	=	the new static run-up duration (seconds), and
	% RPM	=	the power type descriptor.

4.2 Implementation Into MCM

The MCM takes the airbase operations as they are created by the BASEOPS program and creates the processing template that NMAP expects. The processing template (NMI file) is a conglomeration of data from the OMEGA 10, OMEGA 11 and MCM components of NOISEMAP. These data include reference noise data, aircraft power profiles and altitude profiles, and aircraft movement data and flight track data.

The MCM takes the BASEOPS Input (BPS) file as input. For the implementation of the new takeoff roll mode the format of the BPS file has been changed to include the takeoff operation static run-up duration. This information is now included in the power profile section of the BPS file.

The MCM has been changed in three areas:

a. The LOAD Module (for passing BPS files)

b. The OMEGA 10 Module (managing the OMEGA 10 reference data extraction process)

c. The NMAP Module (managing the execution of NMAP)

Modifications to the BPS load module are limited to those necessary to accommodate the new BPS file format. This includes a modification to the power profile data structure in the MCM to include a variable for the static run-up duration.

The OMEGA 10 processing routines analyze the flyover power data to reduce duplication in power settings and to create an OMEGA 10 input file. The OMEGA 10 input file is a list of unique aircraft power settings which the OMEGA 10 program uses to extract data from the NOISEFILE reference flyover noise database. These routines now check each flight profile to determine whether it is a takeoff or not. If the current flight profile is a takeoff then the power setting and airspeed of the rotation point is used to create an input file for the OMEGA 11 program. Duplicate power settings and airspeeds are, of course, trapped and the OMEGA 11 program will use the resulting input file to extract the reference noise for static run-up. A noise level adjustment is added to the reference levels to account for number of aircraft engines and the static run-up duration. The routines that manage the execution of the OMEGA 10 program were modified to include the execution of the OMEGA 11 program, to extract the static run-up reference noise data.

The routines that process the NMAP NMI file were modified to include the new static run-up reference data and to create a new keyword, called TORSTK. The MCM also includes a DSEL card with the acceleration correction required for the D6 takeoff roll adjustments. These routines also modify the name of the reference noise data from AL (or PNL) to SSEL (or SEPN). Since the static run-up directivity data includes an adjustment for duration the levels actually represent integrated levels and being identified as such. The "S" in SSEL and SEPN stands for static.

As mentioned previously, a new keyword has been added, the TORSTK keyword, which identifies the reference SSEL (or SEPN) noise data set. Each reference noise data set is uniquely identified by the aircraft identification and the mission number of the flight profile and it is this "ID" that is included after the TORSTK keyword. When NMAP encounters the new keyword the reference noise "ID" will be stored in an array which associates it with a specific flight event.

Since the new D6 model is not a linear one in order to more accurately accommodate the model, the takeoff roll segment of the NMAP flight path must be further segmented. This is accomplished by dividing the takeoff roll distance into three thirds by use of the DSEL card.

The MCM therefore uses the value of distance input through the BPS file into three thirds. Each of these new distances are used to calculate a noise level adjustment at the beginning and end of each of the new takeoff ground roll segments. The distances and noise level adjustments will be specified to NMAP through the DSEL keyword.

Since there is a limit of 20 segments allowed on each flight path, the effect of the addition of the new TRM will be to reduce by two segments the total number of segments available for other flight regimes.

4.3 Implementation Into NMAP

The implementation of the new takeoff roll model into NOISEMAP principally required the creation of a new subroutine to process the TORSTK, STKSEL and STKEPN keywords. These subroutines will read the data associated with each keyword and store the data in an appropriate fashion. These routines were called XTORST, XSSEL, and XSEPN, respectively, and in accordance with NMAP methodology.

Both the XSSEL and XSEPN subroutines read and store the reference noise data as created by the OMEGA 11 program. The format of these data are the same as those previously created by OMEGA 11, however, since a duration adjustment was added to these levels, it was determined that it would be better to indicate in some way that these levels are essentially integrated noise levels. Both the STKSEL and STKEPN data are stored in data structures already existing in the NMAP program for aircraft run-up reference noise data.

The acceleration model as detailed in Section 3 has been implemented by calculating the adjustment at the start-or-roll (SOR) position and the aircraft rotation (ROT) position. These two adjustments are used by NMAP in order to interpolate the adjustment to grid locations that are between the SOR and ROT points.

For aircraft operations that are identified as takeoffs the processing routines responsible for managing the merging of the power, altitude and flight track profiles, namely the PROCES subroutine, is also responsible for checking that the required data exists. Once the appropriate data for this takeoff operation has been found, the actual noise exposure calculations that follow blend fairly efficiently with the other NMAP calculations. The current takeoff roll model in the NMAP program uses a constant directivity adjustment that is imposed on the ground-to-ground propagation data of the aircraft's rotation power and speed. The data were combined in such a way as to "look like" a run-up reference data set, and would then use the run-up processing routines to calculate the noise exposure. By using actual run-up reference data (adjusted for duration and number of aircraft engines) the same processing routines will be used.

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